Microwave radiation with stochastically jumping phase:generation and application to develop a new type of optical radiation sources

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Extensive research has been devoted to the theoretical and experimental investigation of the interaction of charged particle beams with plasma.

In this paper, we describe also the results of the theoretical and experimental investigation of the plasma interaction with microwave radiation with jumping phase that obtained with help of the unique beam-plasma generator (BPG) made in KIPT. This study continues research on behaviour of plasma discharge subjected to microwave radiation with stochastically jumping phase (MWRSJP). The paper is organized as follows. The first section contains introduction and brief review of previous research. In Section 2, it is considered the interaction of a tubular electron beam with the plasma of a so-called helix-plasma waveguide (HPW) being a plasma waveguide placed into a helix slow-wave structure. In order to clarify the relative contributions of plasma and helix to oscillation excitation and power output, we investigated the influence of the helix on the plasma waveguide dispersion properties. In Section 3, it is presented an experimental device layout that was used to study the generation conditions for quasi-cw stochastic oscillations in the decimeter wavelength band. This apparatus consisted of electron-optical and electro-dynamic units, a collector, and a solenoid. In Section 4, in the BPG experimental studies it was measured the electron beam current and energy, working gas pressure, plasma density, power and frequency spectrum of generated microwave oscillations, and the microwave oscillation pulse envelopes. To determine the stochasticity degree of the generated oscillations it was used the realization method followed by Fourier-analysis of oscillations. There are computed the autocorrelation functions, the correlation times, and the integral and differential amplitude distributions. In Section 5, it is considered a comparizon the theoretical results with the experimental data on the collective interaction between the electron beam and the helix-plasma waveguide waves, it is, above all, determined the beam parameters and the plasma density. In section 6, there are considered the experimental parameters of MWRSJP obtained from the BPG. The scheme of measurement of various parameters is given and experimental studies of optical radiation from the plasma discharge initiated by MWRSJP are presented.

Concluding remarks follow at the end.

It was shown in [1-3], both theoretically and experimentally, that the phenomenon of anomalous penetration of microwave radiation into plasma, conditions for gas breakdown and maintenance of a microwave gas discharge, and collisionless electron heating in a microwave field are related to jumps of the phase of microwave radiation. In this case, in spite of the absence of pair collisions or synchronism between plasma particles and the propagating electromagnetic field, stochastic microwave fields exchange their energy with charged particles. In such fields, random phase jumps of microwave oscillations play the role of collisions and the average energy acquired by a particle over the field period is proportional to the frequency of phase jumps.

Gas breakdown and maintenance of a discharge in a rarefied gas by a pulsed MWRSJP were studied theoretically and experimentally in [4, 5], as well as propagation of this radiation within the plasma produced in such a way. The conditions for ignition and maintenance of a microwave discharge in air by MWRSJP were found. The pressure range in which the power required for discharge ignition and its maintenance has its minimum was determined. It was shown that, in the interval of pressures that have a level less than optimal (about 50 Pa for argon), the minimum of MWRSJP breakdown power depends weakly on the working gas pressure owing to several reasons. These reasons are efficient collisionless electron heating, weakening of diffusion and, finally, decrease of elastic and inelastic collisional losses. This allows one to extend the domain of discharge existence toward lower pressures. The intensity of collisionless electron heating increases with increasing rate of phase jumps in MWRSJP. There is an optimal phase jump rate at which the rate of gas ionization and, accordingly, the growth rate of the electron and ion densities reach their maximum. The optimal phase jump rate is equal to the ionization frequency at electron energies close to the ionization energy of the working gas.

The effect of high power pulsed decimeter MWRSJP action on a plasma, produced in a coaxial waveguide filled with a rarefied gas, is investigated with use of the above mentioned BPG [3], which was upgraded for the given experimental conditions. The goal of this research is to study the special features of low pressure discharge initiated by MWRSJP und also optical radiation spectra. For interpretation of the experimental results on the ignition and maintenance of a microwave discharge in air obtained with MWRSJP BPG, a numerical code has been developed. This code allows simulating the process of gas ionization by electrons heated in the MWRSJP field and studying the behaviour of plasma particles in such a field.

Laboratory models of high-power stochastic oscilla-tion generators were implemented using the slow-wave helix-plasma systems with either single or double mo-dified helices (see fig.1). Their performance was investigated. The obtained experimental results (the dispersion properties of helix-plasma waveguides, the frequency spectrum broadening mechanisms, the threshold and critical currents) turned out to be in qualitative agreement with theory.

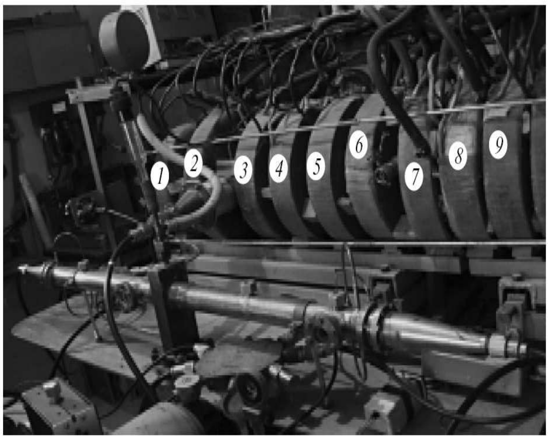

Fig. 1 – The general view of the experimental device with the coaxial waveguide

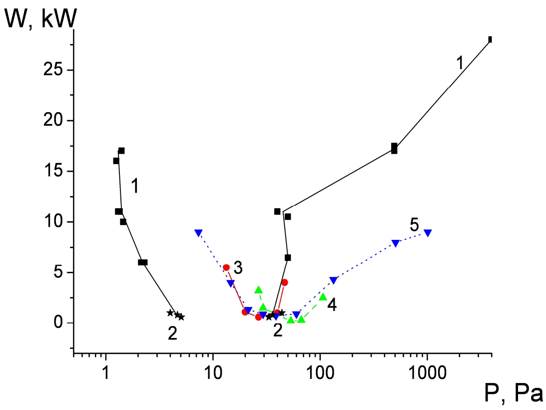

Fig. 2 – Dependences for breakdown power of a microwave signals with a stochastically jumping phase versus a pressure for air in the optimal BPG mode (curves 1 – ■, 2 - *), in the non-optimal BPG mode: for air (curve 3 - •), argon (curve 4 – ▲), helium (curve 5 – ▼), respectively, at narrowband signal.

At the stage of discharge in the coaxial waveguide, the discharge becomes nonuniform along its length due to the strong absorption of MWRSJP. The electric field amplitude decreases by more than one order when approaching to the waveguide exit.

During the maintenance of MWRSJP discharge in the waveguide, gas ionization leads to almost complete decay in the spectrum of the output signal from the coaxial waveguide of the main spectral components of the input microwave signal.

With the distance increasing from the input of MWRSJP into the coaxial waveguide, the discharge optical radiation intensity decreases significantly, becoming inhomogeneous, as well as its cross-section decreases.

With air pressure decreasing, the optical radiation from the discharge becomes more reach with shorter wavelength. Thus, if at the pressure of 20 Pa, the radiation has red colour, then at pressure of 2Pa the radiation becomes blue.

MWRSJP and discharge optical radiation are observed in time almost throughout the pulse duration of electron beam current in BPG.

When the frequency of MWRSJP signal and the frequency of phase jumps are those as observed in the conducted investigations, there is enough to have the magnitude of electric field equals to 50 V / cm, for the creation and maintainence of the discharge in air.

Thus, based on the quantitative indicators, such as the electric field intensity, frequencies of MWRSJP and phase jumps it can be expected the following. The prospective creation of an efficient light radiation source of low power (100 W) in a wide range of air pressure, in which the discharge is ignited and maintained stably, becomes a reality. The main task of future experimental and theoretical research is to optimize the gas mixture for the discharge of quasi-solar optical spectrum.

The developing of a new type of the high efficiency sources of optical radiation with quasi solar spectrum would make a fundamental breakthrough in lighting technology.

The results might also be of some use in connection with additional plasma heating in nuclear fusion devices due the fact that, the electron heating by microwave radiation with jumping phase is collisionless.

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